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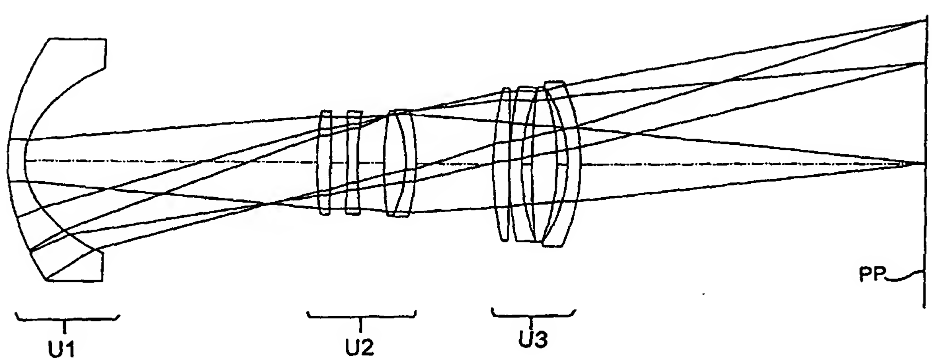

(57) Abstract

Projection lenses for use with pixelized panels, e.g., LCD panels, are provided. The lenses consist in order from their image to their object end of: a first lens unit (U1) composed of plastic, a second lens unit (U2) air spaced from the first lens unit (U1) and consisting of one or more glass lens elements, and a third lens unit (U3) air spaced from the second lens unit (U2) and consisting of one or more glass lens elements. The first lens unit (U1) preferably has at least one aspherical surface, while the lens elements of the second and third lens units (U2, U3) have spherical surfaces. The use of plastic only in the first lens unit and the use of glass only in the second and third lens units, as well as the limitation of aspherical surfaces to the first lens unit, facilitates manufacture and assembly of the projection lens.

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HYBRID PROJECTION LENSES FOR USE WITH PIXELIZED PANELS

FIELD OF THE INVENTION

This invention relates to projection lenses and, in particular, to projection lenses which can be used, inter alia, to form an image of an object composed of pixels, e.g., a LCD. Even more particularly, the invention relates to hybrid projection lenses, i.e., lenses which employ both glass and plastic lens elements, and to an arrangement of such elements which minimizes the cost of manufacture of the projection lens.

BACKGROUND OF THE INVENTION

Projection lens systems (also referred to herein as "projection systems") are used to form an image of an object on a viewing screen. Such systems can be of the front projection or rear projection type, depending on whether the viewer and the object are on the same side of the screen (front projection) or on opposite sides of the screen (rear projection)

The basic structure of a projection lens system for use with a pixelized panel is shown in Figure 3, where 10 is a light source (e.g., a tungsten-halogen lamp), 12 is illumination optics which forms an image of the light source (hereinafter referred to as the "output" of the illumination system), 14 is the object (pixelized panel) which is to be projected (e.g., a LCD matrix of on and off pixels), and 13 is a projection lens, composed of multiple lens elements, which forms an enlarged image of object 14 on viewing screen 16. The system can also include a field lens, e.g., a Fresnel lens, in the vicinity of the pixelized panel to appropriately locate the exit pupil of the illumination system.

For front projection systems, the viewer will be on the left side of screen 16 in Figure 3, while for rear projection systems, the viewer will be on the right side of the screen. For rear projection systems which are to be housed in a single cabinet, a mirror is often used to fold the optical path and thus reduce the system's overall size.

Projection lens systems in which the object is a pixelized panel are used in a variety of applications, including data display systems. Such projection lens systems preferably employ a single projection lens which forms an image of, for example, a single panel having red, green, and blue pixels. In some cases, e.g., large image rear projection systems, multiple panels and multiple projection lenses are use, with each panel/projection lens combination producing a portion of the overall image.

There exists a need in the art for projection lenses for use with pixelized panels which simultaneously have at least the following properties:

(1) a high level of color correction;

(2) low distortion; and

(3) a construction which facilities manufacture and assembly of the lens.

For certain applications, it is desirable for a projection lens having the foregoing properties to also having the following property:

(4) the ability to operate (focus) over a wide range of magnifications (conjugates) while maintaining an efficient coupling to the output of the illumination system and a high level of aberration correction (hereinafter referred to as the "lens' focus range").

A high level of color correction, is important because color aberrations can be easily seen in the image of a pixelized panel as a smudging of a pixel or, in extreme cases, the complete dropping of a pixel from the image. These problems are typically most severe at the edges of the field.

All of the chromatic aberrations of the system need to be addressed, with lateral color, chromatic variation of coma, and chromatic aberration of astigmatism typically being most challenging. Lateral color, i.e., the variation of magnification with color, is particularly troublesome since it manifests itself as a decrease in contrast, especially at the edges of the field. In extreme cases, a rainbow effect in the region of the full field can be seen.

In projection systems employing cathode ray tubes (CRTs) a small amount of (residual) lateral color can be compensated for electronically by, for example, reducing the size of the image produced on the face of the red CRT relative to that produced on the blue CRT. With a pixelized panel, however, such an accommodation cannot be performed because the image is digitized and thus a smooth adjustment in size across the full field of view is not possible. A higher level of lateral color correction is thus needed from the projection lens.

The use of a pixelized panel to display data leads to stringent requirements regarding the correction of distortion. This is so because good image quality is required even at the extreme points of the field of view of the lens when viewing data. As will be evident, an undistorted image of a displayed number or letter is just as important at the edge of the field as it is at the center. Moreover, projection lenses are often used with offset panels, the lenses of the examples being designed for such use. In such a case, the distortion at the viewing screen does not vary symmetrically about a horizontal line through the center of the screen but can increase monotonically from, for example, the bottom to the top of the screen. This effect makes even a small amount of distortion readily visible to the viewer.

Low distortion and a high level of color correction are particularly important when an enlarged image of a WINDOWS type computer interface is projected onto a viewing screen. Such interfaces with their parallel lines, bordered command and dialog boxes, and complex coloration, are in essence test patterns for distortion and color. Users readily perceive and object to

even minor levels of distortion or color aberration in the images of such interfaces.

Property (3) above, i.e., a construction which facilitates manufacture and assembly, is desirable from a logistics and cost point of view.

Projection lenses employing glass and plastic lens elements are known in the art. The glass and plastic elements, however, have not previously been segregated into separate units. As a result, it has not been possible to assemble a projection lens by separately assembling an all plastic unit and one or more all glass units and then combining those units to form the finished projection lens. This inability has increased the costs of projection lenses since the manufacturing procedures and equipment needed to produce plastic lens elements are different from those needed for glass lens elements.

Projection lenses employing aspherical surfaces are also known in the art. However, projection lenses in which aspherical surfaces are only employed in one lens unit, with the rest of the projection lens being free of aspherical surfaces, have not been previously disclosed in the art. In particular, prior projection lenses have employed aspherical surfaces at both the image and object ends of the projection lens, rather than only at the image end. In accordance with the present invention, it has been determined that a high level of aberration correction can be achieved even though aspherical surfaces are used only at the image end of the lens.

This finding in combination with the segregation of the lens into all glass and all plastic lens units further facilitates the economical production of projection lenses since it allows for the provision of an all plastic image side lens unit which contains aspherical surfaces, with the rest of the projection lens being composed of glass lens elements which do not contain aspherical surfaces. As known in the art, it is easier to form an aspherical surface on a plastic lens element than on a glass lens element because plastic can be readily molded.

Optional property (4), i.e., the ability to efficiently operate over a wide range of magnifications (a large focus range), is desirable since it allows the projection system to be used with screens of different sizes and halls of different dimensions without the need to change any of the components of the system. Only the object and image conjugates need to be changed which can be readily accomplished by moving the lens relative to the pixelized panel. The challenge, of course, is to provide efficient coupling to the output of the illumination system and a high level of aberration correction throughout the operative range of magnifications.

The projection lenses described below achieve all of the above requirements and can be successfully used in producing relatively low cost projection lens systems capable of forming a high quality color image of a pixelized panel on a viewing screen.

DESCRIPTION OF THE PRIOR ART

Projection lenses for use with pixelized panels are described in various patents including Taylor, U.S. Patent No. 4,189,211, Tanaka et al., U.S. Patent No. 5,042,929, Yano et al., U.S. Patent No. 5,179,473, Moskovich, U.S. Patent No. 5,200,861, Moskovich, U.S. Patent No. 5,218,480, Moskovich, U.S. Patent No. 5,625,495, Iizuka et al., U.S. Patent No. 5,278,698, Betensky, U.S. Patent No. 5,313,330, and Yano, U.S. Patent No. 5,331,462.

Discussions of LCD systems can be found in Gagnon et al., U.S. Patent No. 4,425,028, Gagnon, U.S. Patent No. 4,461,542, Ledebuhr, U.S. Patent No. 4,826,311, and EPO Patent Publication No. 311,116.

SUMMARY OF THE INVENTION

In view of the foregoing, it is an object of the present invention to provide improved projection lenses for use with a pixelized panel which simultaneously have properties (1)-(3) discussed above and preferably also have property (4). This object is achieved by means of a projection lens which consists in order from its image end to its object end of:

(a) a first lens unit composed of plastic;

(b) a second lens unit air spaced from the first lens unit and consisting of one or more glass lens elements; and

(c) a third lens unit air spaced from the second lens unit and consisting of one or more glass lens elements;

wherein the lens elements of the second and third lens units have spherical surfaces.

In their preferred embodiments, the projection lenses of the invention have some and, most preferably, all of the following characteristics:

(1) the first lens unit comprises at least one aspherical surface;

(2) the first lens unit consists of a single lens element; and/or

(3) the maximum clear aperture of the first lens unit is larger than the maximum clear apertures of both the second and third lens units.

The projection lenses of the invention are preferably designed using the location of the output of the illumination system as a pseudo-aperture stop/entrance pupil of the projection lens (see Betensky, U.S. Patent No. 5,313,330, the relevant portions of which are incorporated herein by reference). In this way, efficient coupling is achieved between the light output of the illumination system and the projection lens.

In accordance with these embodiments, the invention provides a projection lens system which forms an image of an object and comprises:

(a) an illumination system comprising a light source and illumination optics which forms an image of the light source, said image being the output of the illumination system;

(b) a pixelized panel which comprises the object; and

(c) a projection lens of the type described above, said projection lens having an entrance pupil whose location substantially corresponds to the location of the output of the illumination system.

In terms of performance, a preferred level of image quality for the projection lenses of the invention comprises a distortion of less than 1%, more preferably less than 0.5%, a lateral color blur of less than a half of a pixel over the range from 470 nanometers to 630 nanometers, and an axial

color blur of less than two pixels again over the range from 470 nanometers to 630 nanometers. These performance levels for color correction can be applied at the object or at the image, a magnified pixel being used when the criteria are applied at the image. The performance level for axial color blur is less stringent than that for lateral color blur since axial color manifests itself as a symmetric halo which normally is not as readily detected by the user as is lateral color.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1-2 are schematic side views of projection lenses constructed in accordance with the invention.

Figure 3 is a schematic diagram showing an overall projection lens system in which the projection lenses of the present invention can be used.

The foregoing drawings, which are incorporated in and constitute part of the specification, illustrate the preferred embodiments of the invention, and together with the description, serve to explain the principles of the invention. It is to be understood, of course, that both the drawings and the description are explanatory only and are not restrictive of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The projection lenses of the present invention have the general form of a plastic first lens unit (i.e., a first lens unit which consists of one or more plastic lens elements), a glass second lens unit (i.e., a second lens unit which consists of one or more glass lens elements), and a glass third lens unit (i.e., a third lens unit which consists of one or more glass lens elements), where the lens elements of the second and third lens units have only spherical surfaces.

The first lens unit includes at least one aspherical surface and, preferably, multiple aspherical surfaces for use in aberration correction, including correction of spherical aberration, astigmatism, coma, and distortion.

As discussed above, correction of distortion is particularly important for lens systems used with pixelized panels. For the lens systems of the invention, the distortion correction is preferably better than about 1.0 percent and more preferably better than about 0.5 percent. These levels of distortion correction should be maintained throughout the lens' focus range for lens systems which have this feature. In accordance with the invention, it has been found that projection lenses having aspherical surfaces only in their first lens unit are able to achieve these high levels of distortion correction.

For purposes of color correction, the projection lenses will generally include a negative lens element composed of a high dispersion material and at least one positive lens element composed of a low dispersion material. The high and low dispersion materials can be glass or plastic.

In general terms, a high dispersion material is a material having a dispersion like flint glass and a low dispersion material is a material having a dispersion like crown glass. More particularly, high dispersion materials are those having V-values ranging from 20 to 50 for an index of refraction in the range from 1.85 to 1.5, respectively, and low dispersion materials are those having V-values ranging from 35 to 75 for the same range of indices of refraction.

For plastic lens elements, the high and low dispersion materials can be styrene and acrylic, respectively. Other plastics can, of course, be used if desired. For example, in place of styrene, polycarbonates and copolymers of polystyrene and acrylic (e.g., NAS) having flint-like dispersions can be used. See The Handbook of Plastic Optics, U.S. Precision Lens, Inc., Cincinnati, Ohio, 1983, pages 17-29.

Focusing of the projection lenses of the invention can be accomplished in various ways. A preferred approach is to use movement of the entire lens relative to the pixelized panel along with a variation in at least one internal space within the lens. In addition to focusing, the projection lens can also have zoom capabilities as illustrated by the

examples presented below. Conventional mechanisms known in the art are used to move the lens and its component parts during focusing and/or zooming.

Figures 1 and 2 illustrate projection lenses constructed in accordance with the invention. Corresponding prescriptions and optical properties appear in Tables 1 and 2, respectively. HOYA or SCHOTT designations are used for the glasses employed in the lens systems. Equivalent glasses made by other manufacturers can be used in the practice of the invention. Industry acceptable materials are used for the plastic elements. Glass FCD1 used in the lens of Example 2 provides that lens with reduced color aberrations in comparison to the lens of Example 1.

The aspheric coefficients set forth in the tables are for use in the following equation:

$$z = \frac{cy^2}{1+[1-(1+k)c^2y^2]^{1/2}} + Dy^4 + Ey^6 + Fy^8 + Gy^{10} + Hy^{12} + Iy^{14}$$

where z is the surface sag at a distance y from the optical axis of the system, c is the curvature of the lens at the optical axis, and k is a conic constant, which is zero except where indicated in the prescriptions of Tables 1 and 2.

The abbreviations used in the tables are as follows:

EFL	effective focal length
FVD	front vertex distance
f/	f-number
ENP	entrance pupil as seen from the long conjugate
BRL	barrel length
OBJ HT	object height
MAG	magnification
STOP	location and size of aperture stop
IMD	image distance
OBD	object distance
OVL	overall length.

The designation "a" associated with various surfaces in the tables represents an aspherical surface, i.e., a surface for which at least one of D, E, F, G, H, or I in the above equation is not zero; and the designation "c" indicates a surface for which k in the above equation is not zero. All dimensions given in the tables are in millimeters.

The tables are constructed on the assumption that light travels from left to right in the figures. In actual practice, the viewing screen will be on the left and the pixelized panel will be on the right, and light will travel from right to left. In particular, the references in the tables to objects and images are reverse from that used in the rest of the specification and in the claims. The pixelized panel is shown in the figures by the designation "PP".

The correspondence between the various elements and surfaces of the lenses of Tables 1 and 2 and the "first lens unit", "second lens unit", and "third lens unit" terminology discussed above is set forth in Table 3. In particular, in this table, U1 is the first lens unit, U2 is the second lens unit, and U3 is the third lens unit.

As discussed above, the projection lenses of Figures 1 and 2 were designed using the pseudo-aperture stop/entrance pupil technique of Betensky, U.S. Patent No. 5,313,330. In accordance with this approach, the illumination system is used to define the entrance pupil for the projection lens, with the entrance pupil being located at a constant position relative to the pixelized panel for all lens focal lengths and conjugates. The location of this pupil is determined by the substantially parallel light (substantially telecentric light) which passes through the pixelized panel from the illumination system.

The surface labeled "aperture stop" in Tables 1 and 2 constitutes the pseudo-aperture stop of the above Betensky patent. Its location corresponds to the location of the output of the illumination system. As can be seen in the subtables labeled "Variable Spaces," the distance from the pseudo-aperture stop to the pixelized panel is essentially constant for all magnifications of the projection lens systems of Figures 1 and 2 (see the

column labeled "Image Distance"). For the magnifications shown, the variable space which defines the location of the aperture stop relative to the back surface of the projection lens is negative for Tables 1 and 2 corresponding to the illumination output being located within the space defined by the lens' front and back lens surfaces. It should be noted that although preferred, the pseudo-aperture stop approach does not have to be used in the design of the lenses of the invention. Rather, the lenses can be designed using a conventional aperture stop.

As discussed above, the projection lenses of Examples 1 and 2 have both focusing and zooming capabilities. The inclusion of a zooming capability allows for fine tuning of the image to, for example, fully fill a viewing screen.

Although focusing and zooming both involve magnification changes, the magnification changes are achieved in fundamentally different ways. Thus, during focusing, the focal length of the lens remains substantially constant as the image and object conjugates change, and the magnification change is a result of the change in the ratio of those conjugates. During zooming, on the other hand, the focal length changes while the image and object conjugates remain constant, and the magnification change is a result of the change in the focal length.

Positions 1-5 in Tables 1 and 2 illustrate this difference with positions 2, 4, and 5 illustrate focusing of the lens, while positions 1, 2, and 3 illustrate zooming. It should be noted that the lenses of these examples include means for accommodating for changes in the focus of the lens resulting from zooming. In particular, Tables 1 and 2 show some changes in conjugates during zooming which achieve these focus corrections.

The lenses of Tables 1 and 2 each have a focus range (F) of 0.08, where the focus range is given by:

$$F = \max |h_O/h_I| - \min |h_O/h_I|,$$

where h_O is the object height, h_I is the magnified image height, and $\max |h_O/h_I|$ and $\min |h_O/h_I|$ are the maximum and minimum magnitudes,

respectively, of the image-to-object magnification (minification) which the projection lens can achieve while maintaining a desired level of image quality. In particular, the lenses of these tables maintain the preferred level of image quality set forth above over this focus range.

The lenses also have zoom ranges (Z) of 0.108 for Table 1 and 0.112 for Table 2, where the zoom range is given by:

$$Z = 2*(\max |h_I| - \min |h_I|)/(\max |h_I| + \min |h_I|),$$

where $\max |h_I|$ and $\min |h_I|$ are the maximum and minimum magnitudes, respectively, of the image height as a result of zooming about a $|h_O/h_I|$ ratio in the focus range.

As is well known in the art, any lens which is capable of zooming can be "pushed" beyond its intended zoom range. Such "pushing", of course, leads to a degradation in the performance of the lens. The degradation, however, is generally not precipitous and generally does not affect all performance parameters at the same rate. Accordingly, as used herein, the zoom range Z is that range of zooming for which if the range were to be increased by 50% at least at some point in such an increased range, the image quality would fall out of the desired range and/or the movement of lens elements would be restricted by the physical structure of the lens and its supporting structures. In the case of the lenses of Tables 1 and 2, the limiting aberration is distortion, i.e., if the zoom range were to be increased to 0.162 for Table 1 or to 0.168 for Table 2, the distortion would exceed 1%.

In summary, the lenses of the invention achieve all of the desired properties listed above for projection lenses for use with pixelized panels.

Although specific embodiments of the invention have been described and illustrated, it is to be understood that a variety of modifications which do not depart from the scope and spirit of the invention will be evident to persons of ordinary skill in the art from the foregoing disclosure.

TABLE 1

Surf. No.	Type	Radius	Thickness	Glass	Clear Aperture Diameter
1	a	117.8894	12.00000	ACRYLIC	175.00
2	ac	49.7129	196.66640		130.00
3		243.8700	9.00000	FD6	72.55
4		∞	Space 1		72.40
5		-1257.8370	7.00000	NBFD10	71.92
6		276.8531	Space 2		71.94
7		224.4526	15.00000	FC5	73.09
8		-95.9987	7.00000	F8	73.60
9		-156.4273	Space 3		75.17
10		223.8968	11.00000	FC5	105.38
11		∞	0.30000		105.97
12		268.1102	9.00000	FD6	107.04
13		147.0862	7.30000		105.95
14		503.3765	16.50000	FC5	106.07
15		-175.6372	7.36000		107.49
16		-105.1167	9.00000	FD6	107.58
17		-149.8025	Space 4		114.55
18		Aperture stop	Image distance		115.29

Symbol Description

a - Polynomial asphere
c - Conic section

Conics

Surface Number	Constant
2	-6.0000E-01

Even Polynomial Aspheres

Surf. No.	D	E	F	G	H	I
1	-3.0550E-07	2.9273E-11	-6.7828E-16	-4.5421E-19	5.1109E-23	-1.8247E-27
2	-2.4894E-07	1.5645E-11	-1.2814E-14	9.9261E-18	-2.5832E-21	1.9012E-25

Variable Spaces

Pos.	Space 1 T(4)	Space 2 T(6)	Space 3 T(9)	Space 4 T(17)	Focal Shift	Image Distance
1	11.240	17.400	53.580	-269.580	-0.569	503.994
2	11.240	10.270	60.756	-265.987	-0.402	503.994
3	11.240	3.000	67.976	-261.753	-0.100	503.994
4	7.775	10.270	60.756	-257.944	-0.442	503.994
5	12.771	10.270	60.756	-269.299	-0.415	503.994

TABLE 1 (continued)

SYSTEM FIRST ORDER PROPERTIES, POS 1

```
OBJ. HT: -3095.0      f/    4.50 MAG:      -0.0335
STOP:    0.00 after surface 18. DIA:  112.89
EFL:  142.786       FVD:  623.761      ENP:  100.479
IMD:  503.994       BRL:  119.767
OBD: -4205.14       OVL:  4828.90
```

SYSTEM FIRST ORDER PROPERTIES, POS 2

```
OBJ. HT: -2935.0      f/    4.50 MAG:      -0.0350
STOP:    0.00 after surface 18. DIA:  112.84
EFL:  148.995       FVD:  627.297      ENP:  99.4580
IMD:  503.892       BRL:  123.405
OBD: -4202.03       OVL:  4829.32
```

SYSTEM FIRST ORDER PROPERTIES, POS 3

```
OBJ. HT: -2780.0      f/    4.54 MAG:      -0.0367
STOP:    0.00 after surface 18. DIA:  111.79
EFL:  155.789       FVD:  631.591      ENP:  98.5263
IMD:  504.002       BRL:  127.590
OBD: -4197.42       OVL:  4829.01
```

SYSTEM FIRST ORDER PROPERTIES, POS 4

```
OBJ. HT: -1135.0      f/    4.60 MAG:      -0.0900
STOP:    0.00 after surface 18. DIA:  110.39
EFL:  148.702       FVD:  632.101      ENP:  99.3860
IMD:  504.119       BRL:  127.983
OBD: -1597.88       OVL:  2229.98
```

SYSTEM FIRST ORDER PROPERTIES, POS 5

```
OBJ. HT: -7300.0      f/    4.50 MAG:      -0.0140
STOP:    0.00 after surface 18. DIA:  112.88
EFL:  149.125       FVD:  625.625      ENP:  99.5175
IMD:  504.001       BRL:  121.623
OBD: -10596.5       OVL:  11222.2
```

First Order Properties of Elements

Element Number	Surface Numbers	Power	f'
1	1 2	-0.54099E-02	-184.85
2	3 4	0.33323E-02	300.10
3	5 6	-0.37065E-02	-269.79
4	7 8	0.71627E-02	139.61
5	8 9	-0.23062E-02	-433.61
6	10 11	0.21847E-02	457.73
7	12 13	-0.24108E-02	-414.80
8	14 15	0.37267E-02	268.33
9	16 17	-0.20979E-02	-476.68

First Order Properties of Doublets

Element Numbers	Surface Numbers	Power	f'
4 5	7 9	0.47870E-02	208.90

TABLE 2

Surf. No.	Type	Radius	Thickness	Glass	Clear Aperture Diameter
1	a	139.1783	12.00000	ACRYLIC	185.00
2	ac	51.2880	224.88409		137.00
3		246.8481	9.00000	FD6	81.55
4		∞	Space 1		81.37
5		∞	7.00000	NBFD10	80.68
6		252.9223	Space 2		80.35
7		273.0633	17.00000	FC5	80.94
8		-114.4438	7.00000	F2	81.22
9		-179.9972	Space 3		82.21
10		103.7400	22.00000	FC5	103.64
11		-483.1217	0.30000		102.98
12		∞	9.00000	NBFD11	102.09
13		102.3704	8.60000		98.68
14		199.2325	26.50000	FCD1	100.28
15		-95.2652	1.20000		101.61
16		-90.2695	8.50000	NBFD11	101.55
17		-207.3439	Space 4		108.97
18		Aperture stop	Image distance		115.12

Symbol Description

a - Polynomial asphere
c - Conic section

Conics

Surface Number	Constant
2	-6.0000E-01

Even Polynomial Aspheres

Surf. No.	D	E	F	G	H	I
1	-3.2280E-07	3.3804E-11	-6.7708E-16	-4.3472E-19	4.8435E-23	-1.5927E-27
2	-3.1725E-07	5.6735E-12	-1.3489E-14	1.0145E-17	-2.6514E-21	2.0405E-25

Variable Spaces

Pos.	Space 1 T(4)	Space 2 T(6)	Space 3 T(9)	Space 4 T(17)	Focal Shift	Image Distance
1	11.518	20.760	48.230	-249.990	-0.573	504.035
2	11.518	11.522	57.514	-245.654	-0.382	504.035
3	11.518	3.000	65.983	-241.090	-0.100	504.035
4	7.775	11.522	57.514	-237.388	-0.392	504.035
5	13.252	11.522	57.514	-249.113	-0.442	504.035

TABLE 2 (continued)

SYSTEM FIRST ORDER PROPERTIES, POS 1

```
OBJ. HT: -3110.0      f/    4.50 MAG:      -0.0333
STOP:    0.00 after surface 18. DIA:  112.95
EFL:  142.220      FVD:  687.538      ENP:  103.574
IMD:  504.035      BRL:  183.503
OBD: -4205.20      OVL:  4892.73
```

SYSTEM FIRST ORDER PROPERTIES, POS 2

```
OBJ. HT: -2935.0      f/    4.50 MAG:      -0.0350
STOP:    0.00 after surface 18. DIA:  112.89
EFL:  149.045      FVD:  691.766      ENP:  102.743
IMD:  503.882      BRL:  187.884
OBD: -4200.19      OVL:  4891.95
```

SYSTEM FIRST ORDER PROPERTIES, POS 3

```
OBJ. HT: -2782.0      f/    4.54 MAG:      -0.0367
STOP:    0.00 after surface 18. DIA:  111.85
EFL:  155.824      FVD:  696.383      ENP:  102.110
IMD:  503.988      BRL:  192.395
OBD: -4195.98      OVL:  4892.36
```

SYSTEM FIRST ORDER PROPERTIES, POS 4

```
OBJ. HT: -1135.0      f/    4.60 MAG:      -0.0900
STOP:    0.00 after surface 18. DIA:  110.42
EFL:  148.714      FVD:  696.417      ENP:  102.808
IMD:  504.011      BRL:  192.406
OBD: -1594.60      OVL:  2291.02
```

SYSTEM FIRST ORDER PROPERTIES, POS 5

```
OBJ. HT: -7300.0      f/    4.50 MAG:      -0.0140
STOP:    0.00 after surface 18. DIA:  112.95
EFL:  149.198      FVD:  690.202      ENP:  102.752
IMD:  504.042      BRL:  186.159
OBD: -10598.6      OVL:  11288.8
```

First Order Properties of Elements

Element Number	Surface Numbers		Power	f'
1	1	2	-0.58053E-02	-172.26
2	3	4	0.32921E-02	303.76
3	5	6	-0.33184E-02	-301.35
4	7	8	0.59780E-02	167.28
5	8	9	-0.19045E-02	-525.07
6	10	11	0.56570E-02	176.77
7	12	13	-0.77185E-02	-129.56
8	14	15	0.75026E-02	133.29
9	16	17	-0.47840E-02	-209.03

First Order Properties of Doublets

Element Numbers		Surface Numbers		Power	f'
4	5	7	9	0.40231E-02	248.57

TABLE 3

Example	U1	U2	U3
1	S1 - S2	S3 - S9	S10 - S17
2	S1 - S2	S3 - S9	S10 - S17

What is claimed is:

1. A projection lens for forming an image of an object, said lens consisting in order from its image end to its object end of:

(a) a first lens unit composed of plastic;

(b) a second lens unit air spaced from the first lens unit and consisting of one or more glass lens elements; and

(c) a third lens unit air spaced from the second lens unit and consisting of one or more glass lens elements;

wherein the lens elements of the second and third lens units have spherical surfaces.

2. The projection lens of Claim 1 wherein the first lens unit comprises at least one aspherical surface.

3. The projection lens of Claim 1 wherein the first lens unit consists of a single lens element.

4. The projection lens of Claim 1 wherein the second lens unit consists of a plurality of glass lens elements.

5. The projection lens of Claim 1 wherein the third lens unit consists of a plurality of glass lens elements.

6. The projection lens of Claim 1 wherein the maximum clear aperture of the first lens unit is larger than the maximum clear apertures of both the second and third lens units.

7. A projection lens system for forming an image of an object, said system comprising:

(A) an illumination system comprising a light source and illumination optics which forms an image of the light source, said image of the light source being the output of the illumination system;

(B) a pixelized panel which comprises the object; and

(C) the projection lens of Claim 1, 2, 3, 4, 5, or 6.

8. The projection lens system of claim 7 wherein said projection lens has an entrance pupil whose location substantially corresponds to the location of the output of the illumination system.

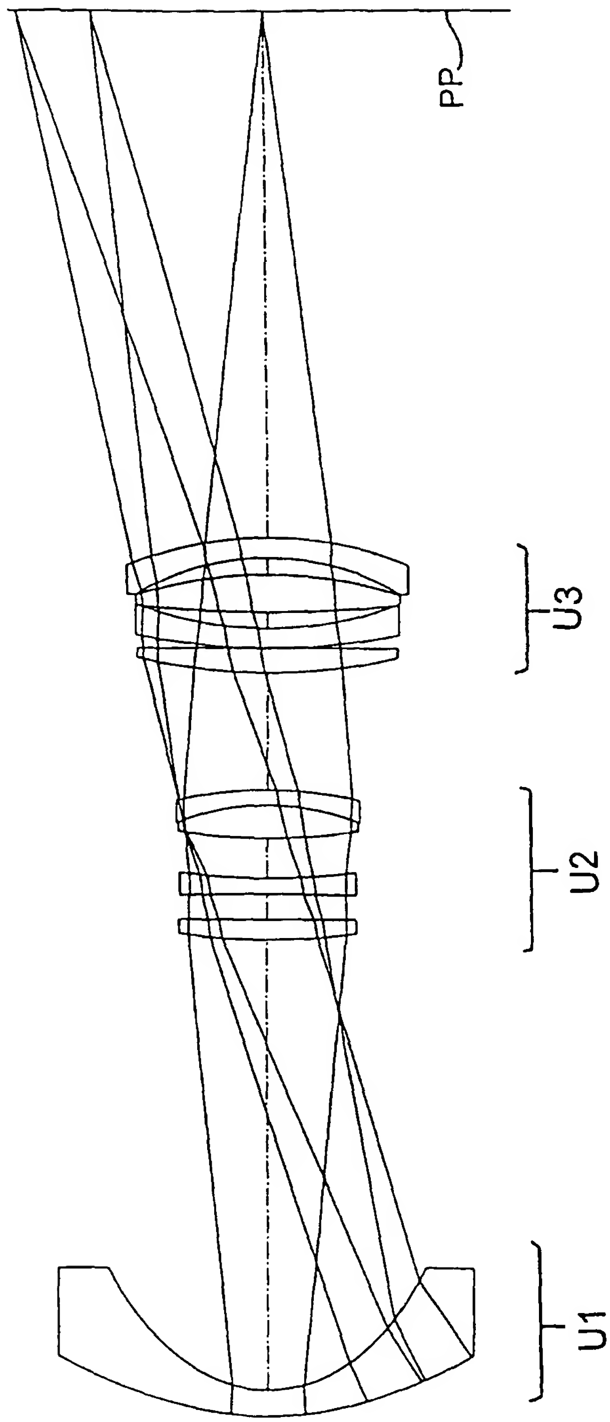

FIG. 1

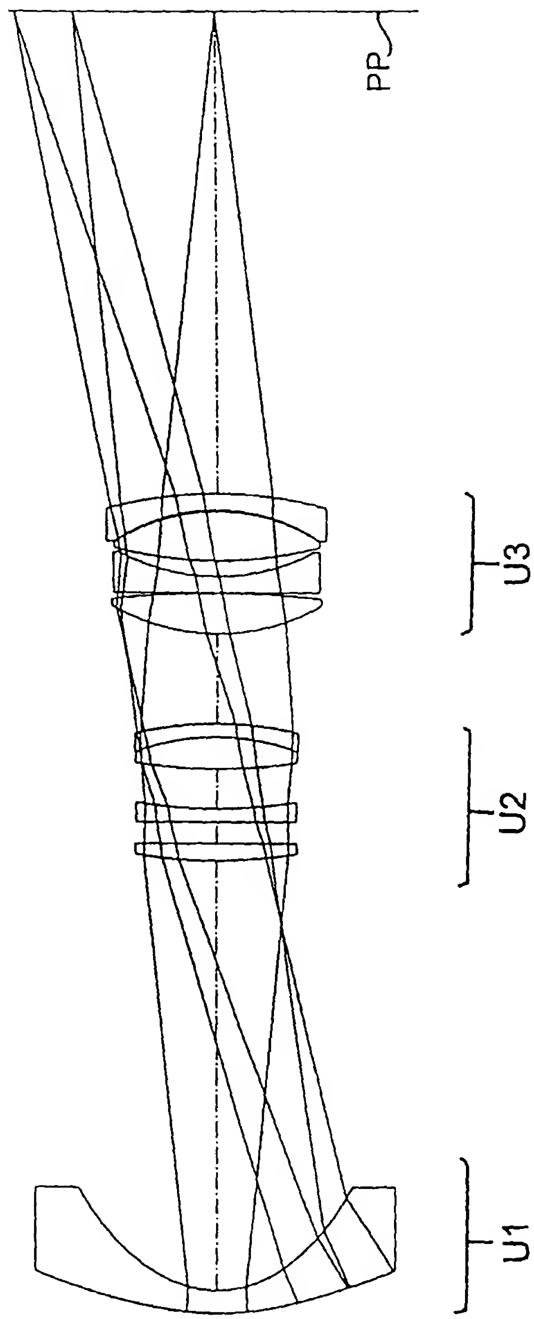

FIG. 2

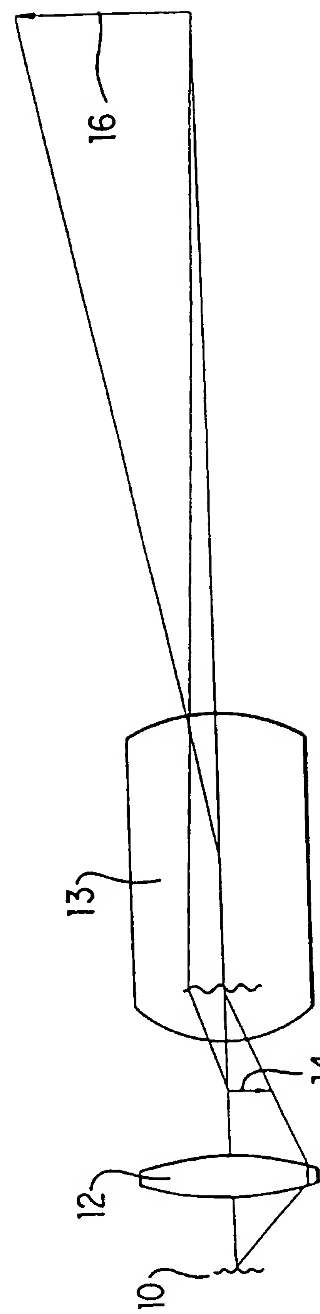

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/01873

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G02B 03/00, 09/00
US CL :359/649, 650, 651
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/649, 650, 651

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
search items: project?(3w)system!, lens?, plastic, glass, aspheric?, spheric?, entrance pupil

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 61-205909 A (HITACHI LTD) 9 December 1986 (09.12.86), abstract, figure 1.	1-3, 6-8
Y	US 2,468,564 A (LUNEBURG) 26 April 1949 (26/04/49), see entire document.	1-3, 5-8
Y	US 4,526,442 A (BETENSKY) 2 July 1985 (02/07/85), see entire document.	1-3, 7
Y	US 5,442,484 A (SHIKAWA) 5 August 1995 (05/08/95), embodiment 21 in Table 21, figure 22 and the accompanying text.	1, 2, 5-8
Y	US 4,704,009 A (YAMAMOTO ET AL) 3 November 1987 (03/11/87), see entire document.	1-3, 7
A	US 4,548,480 A (YAMAMOTO ET AL) 22 October 1985 (22/10/85), see entire document.	1-8

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 MAY 1998	23 JUN 1998

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/01873

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,564,269 A (UEHARA) 14 January 1986 (14/01/86), see entire document.	1-8
A,P	US 5,625,495 A (MOSKOVICH) 29 April 1997 (29/04/97), see entire document.	1-8
A,P	US 5,659,424 A (OSAWA ET AL) 19 August 1997 (19/08/97), see entire document.	1-8